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Corresponding Author: Dr. Giacomo Antonioni, Ph.D.

Corresponding Author's Institution: University of Bologna

First Author: Ada Saracino, Ph.D.

Order of Authors: Ada Saracino, Ph.D.; Matteo Curcuruto, Ph.D.; Giacomo Antonioni, Ph.D.; Marco G Mariani, Ph.D.; Dina Guglielmi, Prof.; Gigliola Spadoni, Prof.

Abstract: This study introduces a new reward system for enhancing safety during work activities, by improving workers' motivation in performance and thereby reducing occupational accidents. The reward system is based on a safety incentive that can be defined by means of two parameters: the worker behavior, which is measured especially in terms of proactivity (namely workers' attitude in reporting potentially hazardous situations) and the consequences that could be avoided thanks to the reporting activity. In doing this, the fuzzy logic theory can be usefully applied, because it offers the opportunity to quantify the two parameters taking into account their vagueness, through the concept of degree of membership and then it also allows to combine them into the final value of the safety incentive through a Fuzzy Inference System (FIS). The model, named "Proactivity-and-Consequence Based Safety Incentive" (PCBSI), has been tested in an Italian chemical plant, with the purpose to evaluate its effectiveness.

Suggested Reviewers: Stacey Conchie

Micaela Demichela

Response to Reviewers: Modifications to the text according to reviewers' comments can be found in the attached file

Cover Letter

Bologna, 12/05/2015

To J. L. Wybo

Editor-in-Chief, Safety Science

Dear Mr. Wybo,

Following the suggestions of the reviewers we are submitting a completely revised version, of the manuscript "Proactivity-and-consequence-based safety incentive (PCBSI) developed with a fuzzy approach to reduce occupational accidents" by Saracino et al.

We look forward to hearing from you at your earliest convenience.

We confirm that this manuscript has not been published elsewhere and is not under consideration by another journal.

All authors have approved the manuscript and agree with its submission to Safety Science.

With my best regards,

Sincerely yours,

Giacomo Antonioni, PhD

List of revisions

Final revision

- *The authors have summarized the main concepts in the section 1 (Introduction and background) with the aim to bring the word count down to about 8,000 and also to give justification for the study more briefly. Also some other sentences in different sections were shortened in the document in order to respect the word count.*

Revisions due to reviewers' comments.

- *The text about description of the Fuzzy Logic Theory has been reduced, in particular some critical points within section 3 (Methodology and fundamentals) have been improved and the text modified according to the comment number 2 and 3 of Reviewer 1.*
- *Figure 5, though strictly correlated with the application of fuzzy logic theory, for which an extensive literature exists, has been better described (highlighted in section 4 case study).*
- *Accordingly to comment 4 of Reviewer 1, the description about safety incentive systems has been integrated in paragraph 2.3.*
- *English has been revised and grammar issues have been modified according to comments of Reviewers.*
- *Section 2.1 (Key-attributes of proactive behaviour) has been condensed using a synthetic way accordingly to comment 2 of Reviewer 2.*
- *The section previously named "Results and discussion" actually included also the conclusions, now a new "Conclusions" section has been added.*
- *References have been reviewed and corrected.*
- *The text has been changed in several parts in order to clarify that PCBSI model is an original methodology developed by the authors.*

Proactivity-and-consequence-based safety incentive (PCBSI) developed with a fuzzy approach to reduce occupational accidents

1. Introduction and background

Human factors, risk perception and workers' behavior play a very important role in the occurrence of accidents (e.g. Reason, 1997); Griffin and Neal (2000) argued that safety motivation also plays an important role as a precursor of safety behaviour, since the term "safety motivation" refers to an individual willingness to exert effort to enact safety behaviors. Thus employees should be motivated to work in a safe manner and to participate in safety activities.

One of the most important tools for improving workers motivation is a reward distribution system, whose correct definition and implementation could decrease the occurrence rate of occupational accidents. As a matter of fact, different studies have shown the relationship between lost workdays, time loss for injuries, accident costs and the use of incentives and of feedback to improve safety: e.g. Haines V. Y. (2001) observed that incentives are associated with a number of positive outcomes (e.g. reduction of accidents). Other similar studies (McAfee and Winn, 1989) found that incentives and feedback successfully improve safety conditions or reduce accidents. Thus a safety reward system has to be considered as an important aspect of company organization (Griffin et al. 2014).

The importance of employees' participation has been recognized as a fundamental aspect of safety performance in organizational settings (Griffin and Neal, 2000) and a commitment-based (or participative) approach in safety promotion should be based on a proactive worker contribution and it goes beyond a simple compliance-based passive contribution (Barling and Hutchinson, 2000).

On the basis of these considerations, in this work a correlation between workers' participation and a safety reward system is proposed; the correlation is based on a specific kind of participatory contribution by workers in safety promotion, which can be considered a form of proactivity, and which can be measured for instance through the spontaneous risk-reporting activities by the employees. Reporting activities can be translated into the risk perceived by workers, who can produce a risk-report spontaneously when he/she observes damages, malfunctions, hazards or an unsafe work condition in the surrounding environment. But each situation could have a different degree of hazard, thus information gathered from a report can also help in the evaluation of the hypothetical damage that the observed situation would have caused.

If reports are assessed on the basis of their quality in terms both of proactivity and of potential consequences, the company may obtain benefits from this kind of workers' participation such as avoided damages, decreased accidents and improved safety. Therefore, a worker who produced a good report both in terms of proposed solutions to the problem and of importance of the avoided hazard should be rewarded by the company for his/her behaviour through an incentive (not necessarily economic).

The proposed method, which has been called PCBSI (Proactivity-and-Consequence Based Safety Incentive), can be seen as a new approach for enhancing safety in workplaces and consequently for reducing the costs of accidents for the company and, beyond the definition of a safety incentive, this tool could also be useful for a systematic assessment of the reports.

In order to achieve this goal a multidisciplinary approach was required for two main reasons: firstly in order to investigate the use of techniques for behavior modification to improve safety and to understand the effect of workers' participation; secondly, in order to define a

Comment [A1]: Reviewer 1
Comment #2: Improvement of the structure and condensation of main concepts

measure for the parameters of the model through the application of the fuzzy logic theory, thanks to its ability in facing uncertainty and vagueness typical of human behavior. Thus, in this study, both engineering and psychology approaches have been conveniently applied in order to develop a method that can enhance occupational safety.

2. Theoretical Framework

Theoretical aspects of proactivity will be discussed hereinafter since they are the starting point for the definition of the assessment procedure. Then a specific methodology to quantify the consequences will be introduced, and finally a brief review about safety incentives and about the aspects related to their influence on the health and safety performance will be described.

2.1 Key-attributes of proactive behavior

In conceptualizing key attributes of proactive behavior in occupational safety domain, three general features, recognized in organizational literature, can be identified (Parker and Collins, 2010): proactive behavior by individuals refers to self-initiated, anticipatory and taking charge of the improvement of the workplace.

Firstly, proactive behavior by employees does not need to be formerly prescribed to be enacted, nor it requires detailed instructions or requests, therefore it could be conceptualized as self-started and self-determined. Despite the impossibility to predict in advance every form of risk factor in a complex work environment, participative behaviors are strongly recommended by managements. Self-started initiative by operators may become essential when standardization does not sufficiently cover all possible situations and could lead to threats for safety.

Secondly, a proactive behavior should be anticipatory and future oriented and implies to act in advance to a future situation, rather than just reacting to solve contingent problems or adjusting to an unpredictable situation. This second attribute of proactivity underlines an implicit performance dimension by safety management systems in organizations, which becomes relevant if high reliability safety conditions over time should be held (Weick and Sutcliffe, 2011).

Thirdly, proactive behaviors are intrinsically meant to create improvements to the actual work and organizational situation and to make things happen rather than just waiting for something to happen for the initiative of someone else. As argued by Morrison and Phelps (1999), "taking charge" entails voluntary and constructive efforts, by individual employees, to effect organizationally functional change with respect to how work is executed within the contexts of their jobs, work units, or organizations.

Degrees of proactivity in risk-reporting

These three typical attributes were considered in order to develop a measure of proactive behaviour in risk reporting within occupational safety. Specifically two theoretical frameworks have been selected as starting points in order to define different levels of proactivity: the model of Parker and Collins (2010) on attributes of proactive behavior and the model of Hollnagel et al. (2011) on safety resilience capabilities. Both theoretical models developed a rating scale (reported in the 2nd and 3rd column of Tab. 1), starting from these scales and considering the key attributes of proactivity, a new behaviourally anchored rating scale, ranging from one to five, has been developed for proactivity (first column of Tab. 1).

Comment [A2]: Reviewer 2
Comment #2: "section *needs condensing, using a more synthetic way of presenting the material ...*"
Section has been modified accordingly.

Types of risk-reporting: Proactivity levels of workforce participation in risk management	Attributes of proactive behavior (see Parker & Collins, 2010)	Safety resilience capabilities (see Hollnagel et al.,2011)
Level one Spontaneous reporting activities of contingent risk factors in the workplace	Spontaneousness Low proactivity	Monitoring (<i>addressing the critical</i>) monitoring what happens, and recognizing if something changes to affect the operative abilities
Level two Self-started problem solving to correct current discrepancies from the standards	Self-started Undertaking a course of actions without no need to be asked to act	Responding (<i>addressing the actual</i>) reacting to regular and irregular variability and disturbances,
Level three Anticipatory problem prevention related to the possible future consequences of risk factors	Future-oriented Acting in advance of a future situation, rather than just reacting	Anticipating (<i>addressing the potential</i>) envisioning developments that lie further into the future, beyond the current operations
Level four Initiatives and suggestions for safety improvement of the current risk management	Taking-charge Taking control and causing something to happen, rather than just adapting or waiting for something to happen	Learning (<i>addressing the factual</i>) Improving future performance experimenting changes as results of new experiences
Level five Generalization of the stimulated improvement in the broader organization setting	Observable improvement outcomes	--

Table 1: Degrees of proactive participation in risk management: conceptual foundations and paradigm comparison

Since in organizational behaviors, proactive ones are characterized by being self-started, anticipatory and taking charge (Parker and Collins, 2010), being the latter the most important because it can generate improvement and a generalized learning, as argued by Griffin et al. (2007), proactivity must not be only “taking charge”, but it must also create a visible impact. Thus in this study the “taking charge” attribute is further splitted into two levels, so that the first include the actions that create a generalized impact in terms of change and actual improvement of workplace safety (level five) and in the second only the actions limited to “taking charge” are considered (level four). Then, since both anticipation and learning are considered typical elements of proactivity in ergonomics (Hollnagel et al., 2011; 2006), intersecting ergonomics and organizational behavior, the aspect of learning is implicitly considered as a vehicle for positive change, while the anticipation element (level three) is assumed to be below the “taking charge” and above the “self-started” level. Finally, a minimum degree of proactivity is assumed for those reports simply related to the formal pressure (if reporting is a statutory requirement, the omission of which is punishable, it cannot be a proactive action, as supported in scientific literature); however, a distinction is made, by definition, between compliance and proactivity, so the basic level (or level one) of

proactivity will be simply a spontaneous (not compulsory) reporting of a contingent situation, while the second level implies at least a self-started problem solving activity.

In summary, intermediate levels of proactivity will be considered, on the basis of the increasing presence of self-started proactive problem solving activity to address the risk and anticipatory envisioning that allows the prevention of possible future consequences associated with a specific risk, and the final level of proactivity is here defined as the extension of generalizability of the employees' stimulation to the broader organizational context.

The final five levels of proactivity are reported in Table 1; note that, since in many organizational settings risk reporting could be considered to some extent an expected or mandatory activity, these levels could be changed accordingly.

These five levels can be seen as a rating scale with behavioural anchors; Behaviourally Anchored Rating Scales (or BARS, Grotte, 1996) places behavioural statements reflecting critical incidents at different places on the rating scale according to their effectiveness level. BARS is one of the methods with greater validity and accuracy for human performance assessment (Mariani, 2011) because it is an evaluation method that aims to combine the benefits of narratives critical incidents, and quantified ratings by anchoring them to a quantified scale with specific narrative examples.

2.2 Consequences

A risk report usually also contains information, observed during a working task, about a hazardous event, which could have the possibility to induce damage to workers' health and/or other related losses for the company. Damages to workers can range from minor injuries, which simply require the absence from work for few hours or at least for one day, to fatalities, passing through major injuries, for which several days of absence could be required; while potential economic losses can be due to malfunction or rupture of the equipment items or even to the stop of the production. Therefore, the overall damage associated to the reported event should entail the health care costs for the workers and for their absence from work but also the capital and operating costs for of the reparation of the equipment items.

However, for the purposes of the proposed study, the magnitude of potential consequences has been described through the imminence of the actions required to reduce (or eliminate) the hazard. The highest is the priority of the intervention the more important will be the economic loss that the company should withstand if the accident occurs. Thus the magnitude of consequences will be translated into categories of "priority of intervention".

It should be taken into account that, since consequences strictly depend upon the activity under examination, though a general approach could be defined for their assessment, in this work a tailored approach for the chemical plant analysed in the case study will be described in sections 3 and 4.

2.3 Safety incentives

The employees' resistance to change in safety policies is one of the problems that decrease occupational safety (Piderit, 2000), a possible solution, in order to reduce improper routines, is to offer rewards. Effectively, as literature shows, "a positive reinforcement" can be built to fostering safe work behavior (Haines, 2001; Teo et al., 2005). Nevertheless the safety incentives must have an effective assignment criterion. Patrim Datta (2012) in his study about reward systems noted that an ineffective reward distribution system can lead to:

- less motivation in employees for their future activities;
- decrease in future performance of (Ostroff, 1992);

- increased likelihood of litigious behaviors of employees (Balkin, 1992);
- an overall perception of organizational inequity;
- a loss of confidence in the organization's employee competencies (Robbins, 2005).

Hence, under these assumptions, it should be stated that employees that are correctly motivated or committed either to the organization or to the change, show better performance towards safety-related changes. Specifically, as Halloran (1996) pointed out, a successful incentive program should be clearly visible to the workers and its goals and methods carefully explained in order not to reduce the extent of the desired outcome or even increase undesired behaviour.

As a matter of fact an incorrect implementation of a reward system could lead for example to the so-called the "bloody pocket syndrome", which means that workers can hide a cut finger in their pockets, instead of reporting the injury, being worried of losing their chance, or the team's chance, to get some incentive rewarded to the teams or sections with less injuries within the company, as denounced by the European Agency for Safety and Health at Work (OSHA, 2012).

Motivation in workplaces can be extrinsic, intrinsic or a combination of both. Incentives as punishments increase solely extrinsic motivation, which means to do something only for instrumental reasons, because this motivation depends on external factors, and it is the opposite of intrinsic motivation, which means to do something for its proper sake. Clearly it is desirable that employees have an intrinsic motivation for solving safety problem, but when there are not motivations for safety-related changes the first step is to increase the external motivation with incentives as the self-determination theory model explains (Deci & Ryan, 2002). As Probst and Brubaker found (2001) extrinsic motivation has both direct and indirect effects on safety related behaviors in workplaces. The same authors found also that when extrinsic motivation in complying with safety policies is reduced, so do the behaviors associated with such compliance.

To encourage workers with an incentive based on their production of risk reports, even if sometimes the reporting could be unnecessary and the hazard could be unimportant, can be seen as a good trade-off between both kinds of motivation.

The types of incentives, which influence the change in safety, are various: like feedback, goal setting (Duff et al., 1994), cash awards, bonus vacation, praise, public recognition, information and participation. In this study the incentive has only a symbolic meaning, thus it can be converted in an extrinsic or monetary reward, which is assigned to an employee on the basis of his/her performance in terms of proactivity and of avoided consequences of the risk report, as explained in the following.

3. Methodology and fundamentals

Different Fuzzy Logic methods have been successfully applied in many real-world applications, because it does a good job in trading off between significance and precision. Moreover, human reasoning can be described by fuzzy logic well over Boolean approach, because in fuzzy systems qualitative, imprecise and uncertain information are processed through linguistic variables, which are based on blurred rules, closer to human reasoning.

The use of fuzzy logic in different aspects of safety and reliability analysis has been discussed in a number of papers because it is a tool that provides a decision framework that incorporates imprecise judgments inherent in the evaluation process (Bowles & Pelaez, 1995; Gentile, Rogers, & Mannan, 2003; Geymar & Ebecken, 1995; Karwowski & Mital, 1986; Markowski, 2006; Salzano & Cozzani, 2006) and it has been applied also for the evaluation of occupational safety (Murè and Demichela, 2009). In this framework the "events" (e.g.

Comment [A3]: Reviewer 1
 Comment #4: "it remains unclear how the use of incentives affected the behavior of the workers during or after the study..."
 The text has been modified accordingly, with the integration of highlights topics in the paragraph.

workers' behaviors) cannot be properly observed, since vagueness occurs and additional real world observations would not reduce this type of uncertainty due to the intrinsic variability of human behavior, thus fuzzy set theory offers an alternative mathematical framework where imprecise phenomena can be modelled by its capability to allow an element to belong simultaneously to more than one category.

In this work the key aspect is to relate the degree of proactivity of the information provided by workers with the hypothetical consequences, in order to obtain a system that incentives worker to a safe behavior. In the next sections, the assessment tool is described through the steps usually required for building a Fuzzy Inference System (FIS), which is the process of formulating the mapping from given inputs to an output using Fuzzy Logic (Zadeh, 1965)

Comment [A4]: Reviewer 1
Comment #3 about the reduction of Fuzzy Theory, also in the next section the text has been modified accordingly.

3.1 FIS based model and variables definition

In Figure 1 is shown the scheme adopted for building the FIS proposed in this work, whose preliminary step is the identification of both input and output variables of the system: the purpose of this model is to combine proactivity and consequences of the risk reports produced by workers (two input variables), in order to obtain a symbolic incentive (the output variable); thus the incentive (I) is a function of two variables, which can be expressed by an equation of the form: $I = f(P; C)$, where P is a measure of the proactivity of workers and C is a measure of consequences or of the entity of the possible damage (e.g. prognoses and days of absence from work, rupture of equipment, loss of production, safety costs, etc...) and it can be translated into the priority of action on a potential hazardous situation. The relationship between I , P and C is implemented through the mathematical tool provided by the FIS, which allows to assess the incentive and to obtain general information about safety behaviors and, implicitly, to monitor the health and safety level of workspaces perceived by workers.

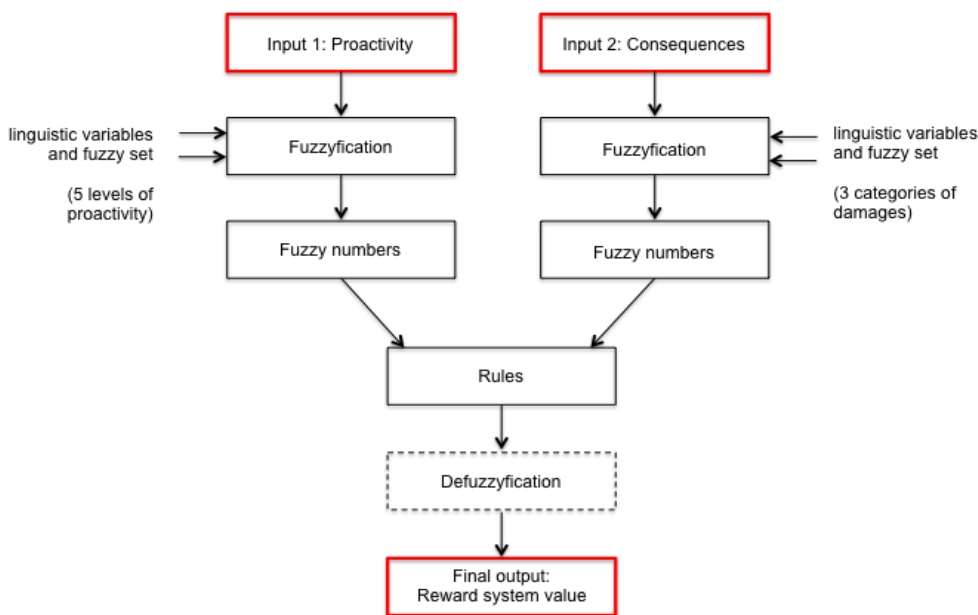


Figure 1: Scheme of the FIS building process for the assessment of the safety incentive.

The measure of both inputs can be gathered from each report, which contains different information about something wrong with reference to a procedure, a behavior or a general

failure of equipment. In fuzzy logic the measure of one variable requires the definition of some “linguistic variables”, which can be words or sentences in a natural or artificial language (Zadeh, 1975), used to describe the original variable.

For rating proactivity the linguistic variables selected are directly those reported in the first column of Table 1 (in the following for the sake of brevity each of them will be identified with the number of its level as reported in the table: L1, L2, etc...) and the procedure for its measure is based on the checklist developed for this study and reported in Appendix A. The checklist is focused on features of workers’ reports that can be used to quantify the proactive level of that behavior and each question has an increasing weight (from 1 to 15), in order to take into account that each one is representative of behaviours with an increasing proactivity level. Thus the sum of the weights of positive answers will be the initial measure of proactivity and the domain of the first variable will be [0; 120].

The second input variable is the priority of intervention required to avoid potential consequences. Three linguistic variables are introduced for its description, priority of intervention can be: “low” (referred as *green* class), “medium” (*yellow* class) and finally “high” (*red* class). This classification comes from the common practice of the company, where the methodology has been firstly applied, and where the priority of intervention is defined through a scale with 3 levels, identified by means of typical traffic lights. The green class identifies events for which the intervention for the reduction of the hazard can be postponed, because the possible related consequences are not severe. Instead the “red” class identifies an urgent intervention for those events that can pose a hazard for the health and safety of workers, or for the process safety, or also an environmental hazard; for instance in this class events that involve the potential spill of a large amount of a dangerous substances can be found. Also this variable is measured through a checklist, reported in Appendix B, which analyses workers’ reports in order to identify the magnitude of the possible consequences of the highlighted event. A preliminary rough knowledge of the colour representing the class is required in order to fill-in the checklist (provided by the company itself), which is divided in three sections, because the procedure requires that only one out of three sections of the checklist must be filled-in.

Finally three linguistic variables, or classes, have been selected for the output: “poor”, “modest” and “remarkable”.

3.2 Fuzzyfication of variables

The fuzzyfication process is done through the use of Fuzzy Sets (FS) and Membership Functions (MFs), a fuzzy set is a class of objects with continuous grades of membership (Zadeh, 1965), which are established through the MFs, that are functions correlating a numerical variable with a “degree of membership” to different linguistic variables.

In building this particular FIS, the fuzzyfication of proactivity passed through the construction of MFs that have been inferred from the meaning of proactivity and from the relationship that exists among its 5 levels (see section 2.1): each proactivity level can be seen as a subset of the previous one and it can be included in the next one. In terms of MFs, the resulting curves are those shown in Figure 2. The first membership function is represented by a rectangle (i.e. it covers the whole “universe of discourse”), because any report can be considered to be at least spontaneous. The MFs of the intermediate levels are trapezoidal and that of the higher level is a triangle. The final result is to assign to each report, not directly its score as it can be calculated straightforward from the checklist, but different degrees of membership to different proactivity levels. For example, a proactivity score of 30 will belong to the 3rd level (“anticipatory”, L3) with a degree lower than one, but it will belong also to classes L2 and L1 with a degree of membership of 1.

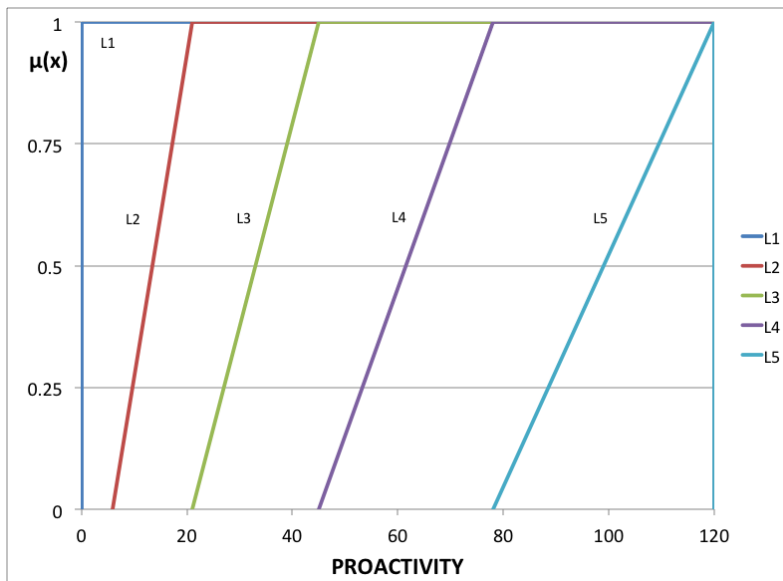


Figure 2. Membership functions for proactivity

Membership functions for the “priority of intervention” are different: three classes characterize this variable of the methodology and 3 trapezoidal functions have been selected (see Fig. 3). MFs have an overlapping zone where the score for the priority of intervention will result in two degrees of membership. The overlapping takes into account the vagueness of risk reporting, because it is a personal interpretation of perceived risk made by a human. For this reason if a report has a high degree of membership to a class, then it may belong with a little degree of membership also to the following one. Thus, even though an “a priori” knowledge of the class is required to answer the checklist, the vagueness of the information is still taken into account in the construction of the MF thanks to fuzzy logic approach.

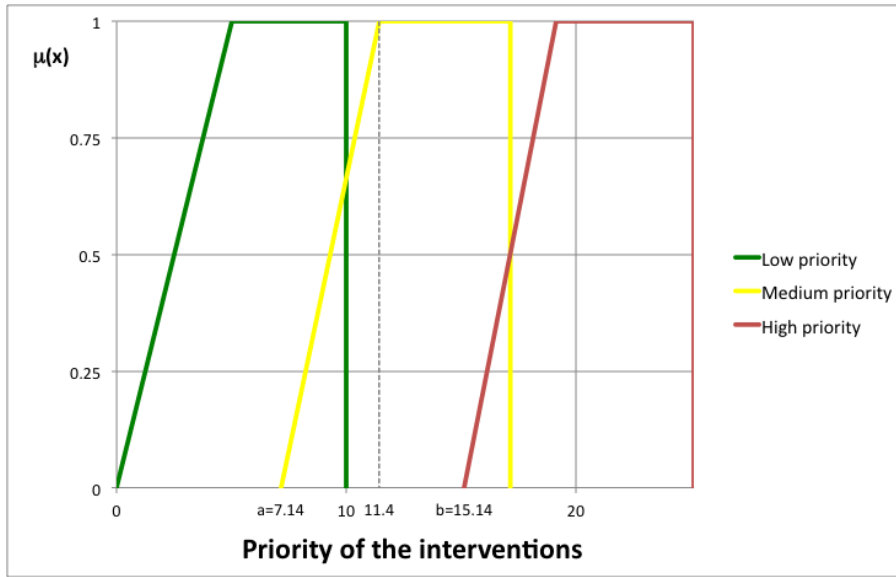


Figure 3. Membership functions for the priority of the intervention

In this particular application (since the quantification of this variable has been adapted to the type of company under consideration, due to the risks associated with the facility) the procedure to obtain a score for the priority of intervention is the following: once the class of the report is known, it is required to answer only to questions in the corresponding section (green, yellow or red) of the checklist. Four different answers to each question are possible, as reported in Appendix B, each corresponding to a score.

The total score of the answers must be added to a constant, which depends on the initial class (see also Figure 3): if the selected section is green the constant is 0; if the section is the yellow one, then the constant is $a = 7.14$; finally if the selected initial class is red, the constant is $b = 15.14$. The values of a and b derive first from having normalized the range for the score of each section, since the number of questions were different from one section to another (9 for the green class, only 7 for the yellow class and 10 for the red one) and then from other assumptions about possible uncertainties in the initial classification. When half of the questions in the green section of the checklist have a completely positive answer, the report can be assumed to be “completely green” and thus it belongs to the green class with the maximum degree of membership (see Figure 3). Then, in order to obtain the graduate shading (fuzzy) between the green and the yellow class, once that a signalling has been classified as yellow, it has been assumed that if only 2 positive answers out of 7 are completely positive, the signalling should be considered only “partly yellow” but still “completely green”. This means that the minimum x value, for which the priority of intervention simultaneously belongs to both classes, can be calculated as: $a = 10 - 2/7 * 10 = 7.14$ (see Fig. 3). The value 11.4 corresponds to the maximum degree of membership to the yellow class and it is given from 3 totally positive answers out of 7 questions ($11.4 = 7.14 + (3/7) * 10$). Similar considerations can be applied when shading from yellow to red class, but the adopted criteria are different and more conservative in order to give more importance to reported situations that can be potentially very dangerous: the number of positive answers to questions in the red section of the checklist that makes a report completely yellow and only partly red is 2 out of 10, while for the complete belonging to the red class at least 4 positive answers are required.

3.3 Fuzzy rules

Once the degrees of membership to the classes of proactivity and of priority of intervention are obtained through respective MFs, classes are used as inputs for the “fuzzy rules”. The fuzzy rules are of decisional type “If...then”, i.e. the symbolic incentive can be given to a worker if the premises are real; therefore, if the proactivity and the priority of intervention of a report activate the terms of the premises, the incentive will be one of the three classes.

In this work only the AND operator was used, also because it translates into a FIS the classical approach used in semi-quantitative risk assessment methodologies. Thus the number of rules that defines the model is $5 \times 3 = 15$ (Table 2). An example of rule is: “if the proactivity of the advisory meets with the features of the 4th level of proactivity (L4) AND the priority of intervention is red (R) then the symbolic incentive is remarkable (r). The consequence “incentive is remarkable” derives from the contemporary activation of the two terms that constitute the premises. The rule matrix reported in Table 2 contains all the rules, from which the class of the incentive for workers can be obtained. The matrix is a typical way of visually representing fuzzy rules when they are all defined using the AND operator, and they have been defined also on the basis of expert judgement by occupational risk analysts and with the help of the HSE management of the company.

Priority				
P P		Green	Yellow	Red
Proactivity	L1	poor (1)	poor (2)	modest (3)
	L2	poor (4)	modest (5)	modest (6)
	L3	modest (7)	modest (8)	remarkable (9)
	L4	modest (10)	remarkable (11)	remarkable (12)
	L5	remarkable (13)	remarkable (14)	remarkable (15)

Table 2. Proactivity-priority-symbolic incentive matrix (rule numbers in brackets)

Finally, the output variable is represented by a class for the symbolic incentive. In Sugeno-type FIS (Sugeno, 1985), which has been selected for this methodology, a crisp output is generated from the fuzzy inputs and can be only either constant or linear. Constant numerical values arbitrarily associated to these classes are 1 for a poor incentive, 2 for the modest and 3 for the remarkable one.

The quantitative solution of the fuzzy system can be obtained using the Matlab fuzzy toolbox, which allows to quickly evaluate the output (incentive) as function of all the possible values in the range of the input variables (proactivity and priority of intervention). Results are reported in Figure 4 where, as expected, the value of the symbolic incentive increases when the level of proactivity and of the priority of intervention increase. From figure 4 is also evident that, since any advisory belongs anyway to the first level of proactivity, the incentive, which is calculated through a weighted average of all the values obtained from the activated rules, will never reach its theoretical maximum value (3, which means “exactly” remarkable). Anyway since numerical values for the incentive have been arbitrarily chosen, the resulting output can be differently scaled on the basis of a further application of the model on a significant number of workers’ advisories.

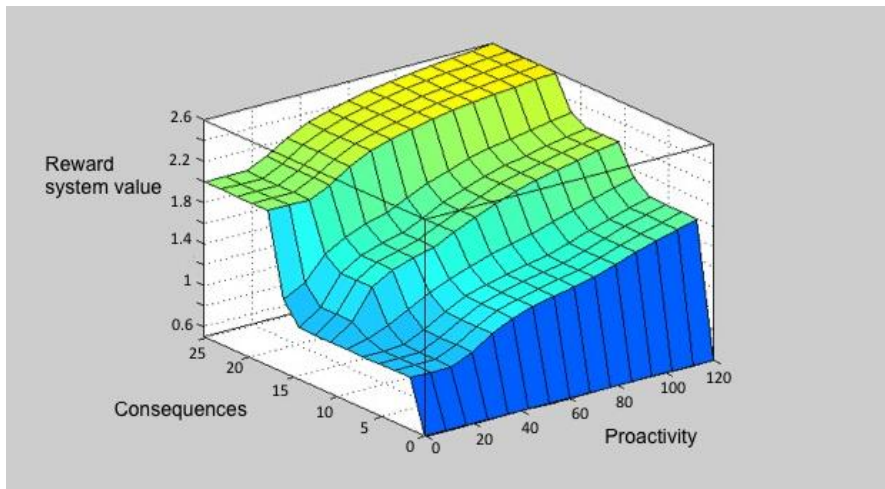


Figure 4. Symbolic incentive as function of both proactivity and priority of intervention

4. Case study

For this case study, the Italian facility of BASF in Pontecchio Marconi has been selected with the purpose to apply for the first time the proposed methodology. Over the period of 2011-2012, 357 events, including potential hazards and loss-of-time injuries, have been signalled by the workers in the register of the reports of the company; however none of them actually resulted in major injuries. Such a large number of reports is also the reason why it is very important for the management of the facility to rank and to organize these data, and this can be done through this methodology, which is able to take advantage of this kind of information. The procedure will be illustrated in detail for 3 selected reports, which have been analysed through the 2 checklists mentioned before and presented in Appendix A and B for proactivity and for consequences respectively. The values of the proactivity and of the priority of the intervention are calculated following the procedure described in the paragraph 3.2. Therefore for each advisory two values are the inputs to the model.

The first risk reporting of potential hazard taken into account mentions:

“The report concerns the discovery of cigarette butts inside a cabinet used for the storage of Individual Protection Devices (IPD).”

It was classified as green in relation with the importance of consequences due to insignificant urgency of the related intervention, then from the answers to the green section of the checklist the resulting score was 1.1. Proactivity is characterized by a value of 6: the first three questions of the checklist are satisfied because it is a spontaneous reporting activity of contingent risk factors in the workplace. The next levels would not be correct for describing the event since it substantially concerns simply the description of a hazard (fire hazard if the workers persist with this habit) and any solution to correct the problem is not proposed. On the basis of the fuzzy rules presented in paragraph 3.3 the resulting safety incentive is 1.

The second proposed risk reporting is:

“The report concerns the difficult access to the industrial refrigerator during maintenance operations. In particular, the operator must slip through pipes and

support structures thus, in case of an accident, first aid to the worker will be difficult.”

The score of this second signalling is 9 for the priority of intervention, thus it actually belongs completely to the green region but also partially to the yellow one, though it was preliminary classified as yellow. Then it satisfies the first and the second level of proactivity because there is a spontaneous reporting activity, and a self-started problem solving process to correct the anomaly can be identified, but there is not an anticipatory attitude related to the possible future consequences. The corresponding score for proactivity is 20. The resulting symbolic incentive is 1.15, which means an incentive slightly higher than “poor” in terms of linguistic variables.

Finally the third report is used to better explain in detail how this FIS works also with the aid of Figure 5. The signalling mentions:

“The report concerns the spill of a product at high T and P from an obstructed air valve. So an injury to the employee that works near the valve is possible.”

The report, on the basis of the answers to both checklists, has a proactivity score of 5 (reported in the leftmost part of Figure 5) and a score of 16.5 for the priority of intervention (central part of the figure). When proactivity is equal to 5 its degree of membership to the first level is equal to 1 and it is 0 to any other proactivity level, but for the priority of intervention, the system assigned a degree of membership equal to 1 to the yellow category and also a non-zero degree of membership to the red one. This means that rules 2 and 3 are activated (highlighted in the box of Figure 5) and that the symbolic incentive has the maximum degree of membership to the class “poor” but it also belongs, though to a lower extent, to the class “modest” (bars in the rightmost part of Figure 5) and the HSE management of the company could still decide whether to assign the first or the second class of incentive. A corresponding numerical value can also be calculated (1.25) from a weighted average (no defuzzification was assumed) of the values obtained for the classes. Though this one was the most severe report in terms of priority of intervention, among the three selected, its low proactivity value does not allow the incentive to be completely at least “modest”.

From the analysis of these three reports it seems quite clear that proactivity plays, as expected, an important role in the definition of the incentive in this reward system, since all the three situations analysed showed a very low level of proactivity and therefore none of them has reached at least completely a “modest” incentive. Nevertheless the model seems to be adequate in taking into account future improvements in the workers’ behavior.

Comment [A5]: Reviewer 1
Comment #3: description of Figure 5
has been improved

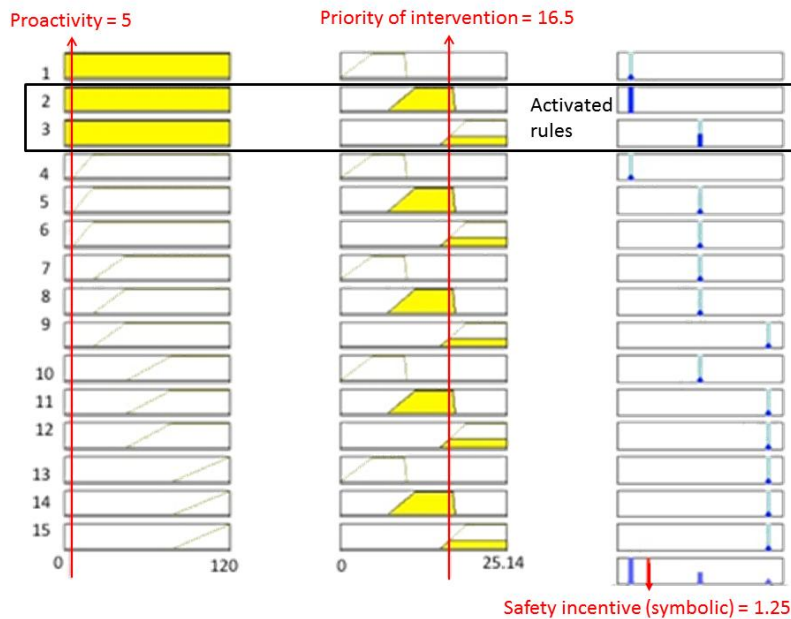


Figure 5. Results for the 3rd selected advisory in the case-study

5. Results and discussion

A first interesting outcome of this first application of PCBSI model was the dramatic increase of reports about potential hazardous events. While some reward programs indirectly discourage workers from reporting accidents and cause an under-reporting problem (because the incentive is assigned on the basis of the absence of injuries), with the proposed approach, the safety incentive is assigned on the basis of the reporting activity itself, which should avoid the accidents occurrence, and thus possibly only an opposite (and less critical) over-reporting situation may be observed from its application. This growth of reporting activity also made available for the company a lot of data, from which monitoring safety standards and planning maintenance interventions, but reports should be conveniently selected and the methodology can also be a useful tool in order to rank and select relevant reports.

PCBSI reward system can also be applied at workgroup level, in order to evaluate the behavioural outcome of working units or teams, especially by setting common goals to teams, because single proactive behaviour is to be differentiated from group level proactive behaviour. Griffin, Neal and Parker (2007) underlined such difference and took into consideration team member proactivity, which is the extent to which an individual engages in self-started and future-oriented behavior in order to influence and modify the way the team works. The authors found that team supportiveness is an antecedent to team member behaviours like team member proficiency, team member adaptability, and team member proactivity. This suggests that a reward system like the one proposed in this work, if integrated in an environment that fosters group supportiveness, should help in increasing group proactivity and ultimately in changing the behavior of teams and single individuals.

Finally, the incentive was measured through a value, which, though symbolic, has an extrinsic meaning, because extrinsic motivation should not be overlooked even if in favour of the more recognized effectiveness of intrinsic one. PCBSI model is therefore a useful tool that enables to

Comment [A6]: Reviewer 4
Comment #4, about benefits
observed in the study

clearly quantify the proactive level of behavior and provides a useful framework to distribute monetary or similar extrinsic rewards also in a measurable and equitable way.

6. Conclusions

This research drew its inspiration from risk reporting activity and from risk perception in workplaces. The method here presented could enrich the range of instruments available to organizations and, among areas of human resources for safety, it could be applied especially in the area of compensation, which brings a certain advantage in terms of competitiveness to the organization (Lawler, 2000) and this is why human resource departments tend to advise the use of these systems.

The aim of the PCBSI model is to build a methodology whose long-term implementation should decrease occupational accidents and injuries. Thus, it is the first step for the realization of a leading method for the prevention of occupational risk. The method is based on the implementation of a reward system (not necessarily monetary), in order to enhance occupational safety, starting from a participatory contribution by workers in safety promotion. The model measures this contribution through spontaneous risk-reporting activities.

It is important to underline that the PCBSI reward program, to be fully effective, should be integrated in an organizational context that is already adopting proper safety education and training, or at least should be introduced in parallel with some organizational change going into such direction.

Under this assumption, a program based on PCBSI presents different advantages, for managements and organizations, as it allows: a) to monitor the actual anticipatory tendency of active risk management at the shop-floor level b) to identify weakest points in safety participations in different organizational sectors c) to identify valid solutions for safety improvement in specific sectors that can be generalized in the whole plant d) to incentive virtuous behaviors and initiatives, by workers and teams.

Some aspects of the methodology can be further improved especially in order to provide a generalized procedure for assessing potential consequences: at management level the overall economic loss avoided thanks to a risk report could be calculated both in terms of lost days due to injuries to workers and in terms of maintenance and repair of damages to the equipment; nevertheless the methodology is also able to identify, at an individual level, where and how to strengthen learning levers, since cases with a low level of proactivity during operations could be pointed out and stimulated using the reward system.

Comment [A7]: Reviewer 2
Comment #6. "Conclusion" section
added and text moved and changed.

Acknowledgements

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Appendix A: Checklist for Proactivity

Possible answers: yes/no (yes = 1, no = 0)

1. Is the operator's advisory actually voluntary (or rather not expected by his job responsibility)?
2. Has the worker spontaneously advised the hazardous event in question (without suggestions from co-workers)?
3. Has the worker advised the event without having previously received specific instructions by the company?
4. Has the worker given suggestions to solve the event?
5. Has the worker tried to solve by him/herself the event?
6. Has the worker tried to reduce the hazard?
7. Was the event actually unpredictable without the worker advisory?
8. Does the worker give useful information to forestall the negative consequences of the event?
9. Does the worker give useful information to forestall the problem in the future?
10. Does the worker give suggestions to face the problem in the future?
11. Does the worker give efficient suggestions to avoid the event in the future?
12. Has the worker actually supplied innovative suggestions (not currently contemplated) to avoid the event in the future?
13. Does the worker suggest or produce a solution that induces an improvement/increase of the safety regarding his work shift?
14. Does the worker suggest or produce a solution, which enhances the safety, that can be extended to the whole department?
15. Does the worker suggest or produce a solution, which enhances the safety, that can be extended to the whole plant?

Appendix B: Checklist for the Priority of the intervention

Possible answers:

totally agree – score = 1

partially agree – score = 0.67

partially disagree – score = 0.33

totally disagree – score = 0

Section one: Green region

1. Does the advisory concern the possible presence of a waste to give back, or a claim?
2. Does the advisory concern the possible presence in the temporary storage area of unsuitable liquids for the waste treatment plant?
3. Does the advisory concern the possible spill (< 10 kg) of a classified substance (like a chemical substance) different from CYC (cyanuric chloride)?
4. Does the advisory concern the possible spill (< 20 kg) of a not classified substance (like water)?
5. Does the advisory concern the possible failure of a RD (Rupture Disk) or safety valve of unclassified equipment?
6. Does the advisory concern a potential first aid for the company employees?
7. Does the advisory concern a potential LTI (Loss Time Injury) for a contract worker (external worker/contractor)?
8. Does the advisory concern a possible deviation from the correct operation of the biological plant?
9. Does the advisory concern an event for which it is necessary to identify actions, but they can be managed without urgency?

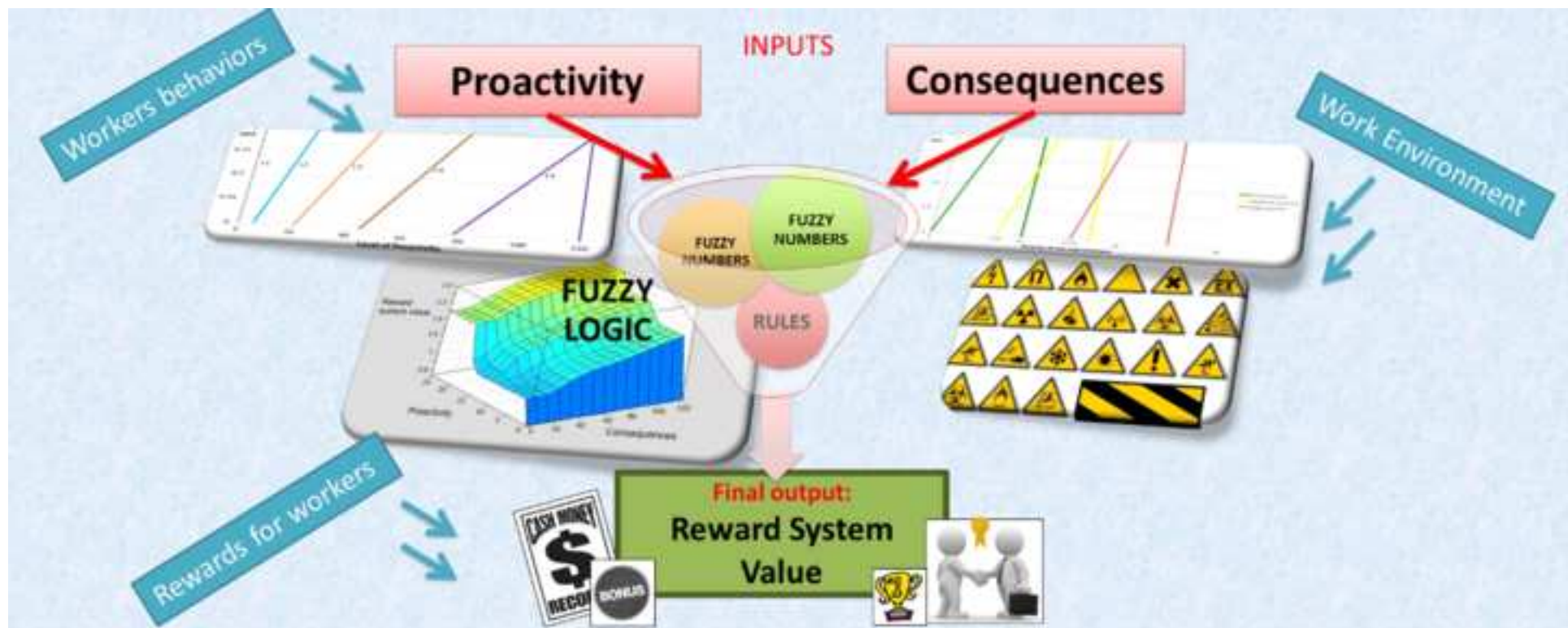
Section two: Yellow region

1. Does the advisory concern the possible spill (> 10 kg but < 100 kg) of a classified substance?
2. Does the advisory concern the possible spill (< 5kg) of CYC (cyanuric chloride)?
3. Does the advisory concern the possible failure of a RD (rupture disk) or of a safety valve on an equipment holding a substance with a Risk Phrase?
4. Does the advisory concern the possible/potential refilling of emergency tank?
5. Does the advisory concern a potential injury for a contract worker (external worker/contractor)? (LTI with first aid for the injury related to the job activity and not generated from site activity interference)
6. Does the advisory concern a potential injury for the employees of the company? (LTI not related to the job activity or an injury, non LTI, related to the job activity)?
7. Does the advisory concern an event for which it is necessary to schedule actions?

Section three: Red region

1. Does the advisory concern the possible spill of BTC ($\alpha\alpha\alpha$ -trichloro toluene) or NH₃ or hot conductive oil (hot diathermic oil)?
2. Does the advisory concern the possible spill (> 5 kg) of CYC?
3. Does the advisory concern the possible spill (> 100 kg) of a classified substance?
4. Does the advisory concern the possible spill (> 2000 kg) of a not classified substance?
5. Does the advisory concern an event which can cause a fire, an explosion/implosion?
6. Does the advisory concern an event which can cause a possible environmental impact?
7. Does the advisory concern a possible RD failure (Rupture Disk) or safety valve failure or concern a possible reaction deviation of a substance with a Risk Phrase?

8. Does the advisory concern an event with possible crossing of inner thresholds for air matrix and water matrix?
9. Does the advisory concern a potential injury (permanent inability or death)? (LTI and first aid for injury related to the job activity for the employees of the company, for the contractors only if it is caused by a site inference activity)
10. Does the advisory concern an event which can draw the media attention?



Highlights

- A methodology for the assessment of a reward or incentive system based on proactivity and on consequence of potential accidents is proposed.
- The methodology takes advantage of a tailored Fuzzy Inference System in order to take into account vagueness of human behaviour
- The methodology has been applied to a case-study through the analysis of some reports from the workers in a process industry

Proactivity-and-consequence-based safety incentive (PCBSI) developed with a fuzzy approach to reduce occupational accidents

Authors: Ada Saracino^a; Matteo Curcuruto^b; Giacomo Antonioni^{a*}; Marco Giovanni Mariani^b; Dina Guglielmi^c; Gigliola Spadoni^a

^a *Department of Civil, Chemical, Environmental and Materials Engineering (DICAM), University of Bologna, Via Terracini 28 – 40131 Bologna - Italy*

^b *Department of Psychology, University of Bologna , Viale Berti Pichat, 5 – 40126 Bologna – Italy*

^c *Department of Education Sciences, «Giovanni Maria Bertin», University of Bologna , Via Fllippo Re 6 – 40126 Bologna – Italy*

*Corresponding author: Tel. +39 0512090230; Fax +39 0512090247

Proactivity-and-consequence-based safety incentive (PCBSI) developed with a fuzzy approach to reduce occupational accidents

1. Introduction and background

Human factors, risk perception and workers' behavior play a very important role in the occurrence of accidents (e.g. Reason, 1997); Griffin and Neal (2000) argued that safety motivation also plays an important role as a precursor of safety behaviour, since the term "safety motivation" refers to an individual willingness to exert effort to enact safety behaviors. Thus employees should be motivated to work in a safe manner and to participate in safety activities.

One of the most important tools for improving workers motivation is a reward distribution system, whose correct definition and implementation could decrease the occurrence rate of occupational accidents. As a matter of fact, different studies have shown the relationship between lost workdays, time loss for injuries, accident costs and the use of incentives and of feedback to improve safety: e.g. Haines V. Y. (2001) observed that incentives are associated with a number of positive outcomes (e.g. reduction of accidents). Other similar studies (McAfee and Winn, 1989) found that incentives and feedback successfully improve safety conditions or reduce accidents. Thus a safety reward system has to be considered as an important aspect of company organization (Griffin et al. 2014).

The importance of employees' participation has been recognized as a fundamental aspect of safety performance in organizational settings (Griffin and Neal, 2000) and a commitment-based (or participative) approach in safety promotion should be based on a proactive worker contribution and it goes beyond a simple compliance-based passive contribution (Barling and Hutchinson, 2000).

On the basis of these considerations, in this work a correlation between workers' participation and a safety reward system is proposed; the correlation is based on a specific kind of participatory contribution by workers in safety promotion, which can be considered a form of proactivity, and which can be measured for instance through the spontaneous risk-reporting activities by the employees. Reporting activities can be translated into the risk perceived by workers, who can produce a risk-report spontaneously when he/she observes damages, malfunctions, hazards or an unsafe work condition in the surrounding environment. But each situation could have a different degree of hazard, thus information gathered from a report can also help in the evaluation of the hypothetical damage that the observed situation would have caused.

If reports are assessed on the basis of their quality in terms both of proactivity and of potential consequences, the company may obtain benefits from this kind of workers' participation such as avoided damages, decreased accidents and improved safety. Therefore, a worker who produced a good report both in terms of proposed solutions to the problem and of importance of the avoided hazard should be rewarded by the company for his/her behaviour through an incentive (not necessarily economic).

The proposed method, which has been called PCBSI (Proactivity-and-Consequence Based Safety Incentive), can be seen as a new approach for enhancing safety in workplaces and consequently for reducing the costs of accidents for the company and, beyond the definition of a safety incentive, this tool could also be useful for a systematic assessment of the reports.

In order to achieve this goal a multidisciplinary approach was required for two main reasons: firstly in order to investigate the use of techniques for behavior modification to improve safety and to understand the effect of workers' participation; secondly, in order to define a

measure for the parameters of the model through the application of the fuzzy logic theory, thanks to its ability in facing uncertainty and vagueness typical of human behavior. Thus, in this study, both engineering and psychology approaches have been conveniently applied in order to develop a method that can enhance occupational safety.

2. Theoretical Framework

Theoretical aspects of proactivity will be discussed hereinafter since they are the starting point for the definition of the assessment procedure. Then a specific methodology to quantify the consequences will be introduced, and finally a brief review about safety incentives and about the aspects related to their influence on the health and safety performance will be described.

2.1 Key-attributes of proactive behavior

In conceptualizing key attributes of proactive behavior in occupational safety domain, three general features, recognized in organizational literature, can be identified (Parker and Collins, 2010): proactive behavior by individuals refers to self-initiated, anticipatory and taking charge of the improvement of the workplace.

Firstly, proactive behavior by employees does not need to be formerly prescribed to be enacted, nor it requires detailed instructions or requests, therefore it could be conceptualized as self-started and self-determined. Despite the impossibility to predict in advance every form of risk factor in a complex work environment, participative behaviors are strongly recommended by managements. Self-started initiative by operators may become essential when standardization does not sufficiently cover all possible situations and could lead to threats for safety.

Secondly, a proactive behavior should be anticipatory and future oriented and implies to act in advance to a future situation, rather than just reacting to solve contingent problems or adjusting to an unpredictable situation. This second attribute of proactivity underlines an implicit performance dimension by safety management systems in organizations, which becomes relevant if high reliability safety conditions over time should be held (Weick and Sutcliffe, 2011).

Thirdly, proactive behaviors are intrinsically meant to create improvements to the actual work and organizational situation and to make things happen rather than just waiting for something to happen for the initiative of someone else. As argued by Morrison and Phelps (1999), “taking charge” entails voluntary and constructive efforts, by individual employees, to effect organizationally functional change with respect to how work is executed within the contexts of their jobs, work units, or organizations.

Degrees of proactivity in risk-reporting

These three typical attributes were considered in order to develop a measure of proactive behaviour in risk reporting within occupational safety. Specifically two theoretical frameworks have been selected as starting points in order to define different levels of proactivity: the model of Parker and Collins (2010) on attributes of proactive behavior and the model of Hollnagel et al. (2011) on safety resilience capabilities. Both theoretical models developed a rating scale (reported in the 2nd and 3rd column of Tab. 1), starting from these scales and considering the key attributes of proactivity, a new behaviourally anchored rating scale, ranging from one to five, has been developed for proactivity (first column of Tab. 1).

Types of risk-reporting: Proactivity levels of workforce participation in risk management	Attributes of proactive behavior (see Parker & Collins, 2010)	Safety resilience capabilities (see Hollnagel et al., 2011)
Level one Spontaneous reporting activities of contingent risk factors in the workplace	Spontaneousness Low proactivity	Monitoring <i>(addressing the critical)</i> monitoring what happens, and recognizing if something changes to affect the operative abilities
Level two Self-started problem solving to correct current discrepancies from the standards	Self-started Undertaking a course of actions without no need to be asked to act	Responding <i>(addressing the actual)</i> reacting to regular and irregular variability and disturbances,
Level three Anticipatory problem prevention related to the possible future consequences of risk factors	Future-oriented Acting in advance of a future situation, rather than just reacting	Anticipating <i>(addressing the potential)</i> envisioning developments that lie further into the future, beyond the current operations
Level four Initiatives and suggestions for safety improvement of the current risk management	Taking-charge Taking control and causing something to happen, rather than just adapting or waiting for something to happen	Learning <i>(addressing the factual)</i> Improving future performance experimenting changes as results of new experiences
Level five Generalization of the stimulated improvement in the broader organization setting	Observable improvement outcomes	--

Table 1: Degrees of proactive participation in risk management: conceptual foundations and paradigm comparison

Since in organizational behaviors, proactive ones are characterized by being self-started, anticipatory and taking charge (Parker and Collins, 2010), being the latter the most important because it can generate improvement and a generalized learning, as argued by Griffin et al. (2007), proactivity must not be only “taking charge”, but it must also create a visible impact. Thus in this study the “taking charge” attribute is further splitted into two levels, so that the first include the actions that create a generalized impact in terms of change and actual improvement of workplace safety (level five) and in the second only the actions limited to “taking charge” are considered (level four). Then, since both anticipation and learning are considered typical elements of proactivity in ergonomics (Hollnagel et al., 2011; 2006), intersecting ergonomics and organizational behavior, the aspect of learning is implicitly considered as a vehicle for positive change, while the anticipation element (level three) is assumed to be below the “taking charge” and above the “self-started” level. Finally, a minimum degree of proactivity is assumed for those reports simply related to the formal pressure (if reporting is a statutory requirement, the omission of which is punishable, it cannot be a proactive action, as supported in scientific literature); however, a distinction is made, by definition, between compliance and proactivity, so the basic level (or level one) of

proactivity will be simply a spontaneous (not compulsory) reporting of a contingent situation, while the second level implies at least a self-started problem solving activity.

In summary, intermediate levels of proactivity will be considered, on the basis of the increasing presence of self-started proactive problem solving activity to address the risk and anticipatory envisioning that allows the prevention of possible future consequences associated with a specific risk, and the final level of proactivity is here defined as the extension of generalizability of the employees' stimulation to the broader organizational context.

The final five levels of proactivity are reported in Table 1; note that, since in many organizational settings risk reporting could be considered to some extent an expected or mandatory activity, these levels could be changed accordingly.

These five levels can be seen as a rating scale with behavioural anchors; Behaviourally Anchored Rating Scales (or BARS, Grotte, 1996) places behavioural statements reflecting critical incidents at different places on the rating scale according to their effectiveness level. BARS is one of the methods with greater validity and accuracy for human performance assessment (Mariani, 2011) because it is an evaluation method that aims to combine the benefits of narratives critical incidents, and quantified ratings by anchoring them to a quantified scale with specific narrative examples.

2.2 Consequences

A risk report usually also contains information, observed during a working task, about a hazardous event, which could have the possibility to induce damage to workers' health and/or other related losses for the company. Damages to workers can range from minor injuries, which simply require the absence from work for few hours or at least for one day, to fatalities, passing through major injuries, for which several days of absence could be required; while potential economic losses can be due to malfunction or rupture of the equipment items or even to the stop of the production. Therefore, the overall damage associated to the reported event should entail the health care costs for the workers and for their absence from work but also the capital and operating costs for of the reparation of the equipment items.

However, for the purposes of the proposed study, the magnitude of potential consequences has been described through the imminence of the actions required to reduce (or eliminate) the hazard. The highest is the priority of the intervention the more important will be the economic loss that the company should withstand if the accident occurs. Thus the magnitude of consequences will be translated into categories of "priority of intervention".

It should be taken into account that, since consequences strictly depend upon the activity under examination, though a general approach could be defined for their assessment, in this work a tailored approach for the chemical plant analysed in the case study will be described in sections 3 and 4.

2.3 Safety incentives

The employees' resistance to change in safety policies is one of the problems that decrease occupational safety (Piderit, 2000), a possible solution, in order to reduce improper routines, is to offer rewards. Effectively, as literature shows, "a positive reinforcement" can be built to fostering safe work behavior (Haines, 2001; Teo et al., 2005). Nevertheless the safety incentives must have an effective assignment criterion. Patrim Datta (2012) in his study about reward systems noted that an ineffective reward distribution system can lead to:

- less motivation in employees for their future activities;
- decrease in future performance of (Ostroff, 1992);

- increased likelihood of litigious behaviors of employees (Balkin, 1992);
- an overall perception of organizational inequity;
- a loss of confidence in the organization's employee competencies (Robbins, 2005).

Hence, under these assumptions, it should be stated that employees that are correctly motivated or committed either to the organization or to the change, show better performance towards safety-related changes. Specifically, as Halloran (1996) pointed out, a successful incentive program should be clearly visible to the workers and its goals and methods carefully explained in order not to reduce the extent of the desired outcome or even increase undesired behaviour.

As a matter of fact an incorrect implementation of a reward system could lead for example to the so-called the "bloody pocket syndrome", which means that workers can hide a cut finger in their pockets, instead of reporting the injury, being worried of losing their chance, or the team's chance, to get some incentive rewarded to the teams or sections with less injuries within the company, as denounced by the European Agency for Safety and Health at Work (OSHA, 2012).

Motivation in workplaces can be extrinsic, intrinsic or a combination of both. Incentives as punishments increase solely extrinsic motivation, which means to do something only for instrumental reasons, because this motivation depends on external factors, and it is the opposite of intrinsic motivation, which means to do something for its proper sake. Clearly it is desirable that employees have an intrinsic motivation for solving safety problem, but when there are not motivations for safety-related changes the first step is to increase the external motivation with incentives as the self-determination theory model explains (Deci & Ryan, 2002). As Probst and Brubaker found (2001) extrinsic motivation has both direct and indirect effects on safety related behaviors in workplaces. The same authors found also that when extrinsic motivation in complying with safety policies is reduced, so do the behaviors associated with such compliance.

To encourage workers with an incentive based on their production of risk reports, even if sometimes the reporting could be unnecessary and the hazard could be unimportant, can be seen as a good trade-off between both kinds of motivation.

The types of incentives, which influence the change in safety, are various: like feedback, goal setting (Duff et al., 1994), cash awards, bonus vacation, praise, public recognition, information and participation. In this study the incentive has only a symbolic meaning, thus it can be converted in an extrinsic or monetary reward, which is assigned to an employee on the basis of his/her performance in terms of proactivity and of avoided consequences of the risk report, as explained in the following.

3. Methodology and fundamentals

Different Fuzzy Logic methods have been successfully applied in many real-world applications, because it does a good job in trading off between significance and precision. Moreover, human reasoning can be described by fuzzy logic well over Boolean approach, because in fuzzy systems qualitative, imprecise and uncertain information are processed through linguistic variables, which are based on blurred rules, closer to human reasoning.

The use of fuzzy logic in different aspects of safety and reliability analysis has been discussed in a number of papers because it is a tool that provides a decision framework that incorporates imprecise judgments inherent in the evaluation process (Bowles & Pelaez, 1995; Gentile, Rogers, & Mannan, 2003; Geymar & Ebecken, 1995; Karwowski & Mital, 1986; Markowski, 2006; Salzano & Cozzani, 2006) and it has been applied also for the evaluation of occupational safety (Murè and Demichela, 2009). In this framework the "events" (e.g.

workers' behaviors) cannot be properly observed, since vagueness occurs and additional real world observations would not reduce this type of uncertainty due to the intrinsic variability of human behavior, thus fuzzy set theory offers an alternative mathematical framework where imprecise phenomena can be modelled by its capability to allow an element to belong simultaneously to more than one category.

In this work the key aspect is to relate the degree of proactivity of the information provided by workers with the hypothetical consequences, in order to obtain a system that incentives worker to a safe behavior. In the next sections, the assessment tool is described through the steps usually required for building a Fuzzy Inference System (FIS), which is the process of formulating the mapping from given inputs to an output using Fuzzy Logic (Zadeh, 1965)

3.1 FIS based model and variables definition

In Figure 1 is shown the scheme adopted for building the FIS proposed in this work, whose preliminary step is the identification of both input and output variables of the system: the purpose of this model is to combine proactivity and consequences of the risk reports produced by workers (two input variables), in order to obtain a symbolic incentive (the output variable); thus the incentive (I) is a function of two variables, which can be expressed by an equation of the form: $I = f(P; C)$, where P is a measure of the proactivity of workers and C is a measure of consequences or of the entity of the possible damage (e.g. prognoses and days of absence from work, rupture of equipment, loss of production, safety costs, etc...) and it can be translated into the priority of action on a potential hazardous situation. The relationship between I , P and C is implemented through the mathematical tool provided by the FIS, which allows to assess the incentive and to obtain general information about safety behaviors and, implicitly, to monitor the health and safety level of workspaces perceived by workers.

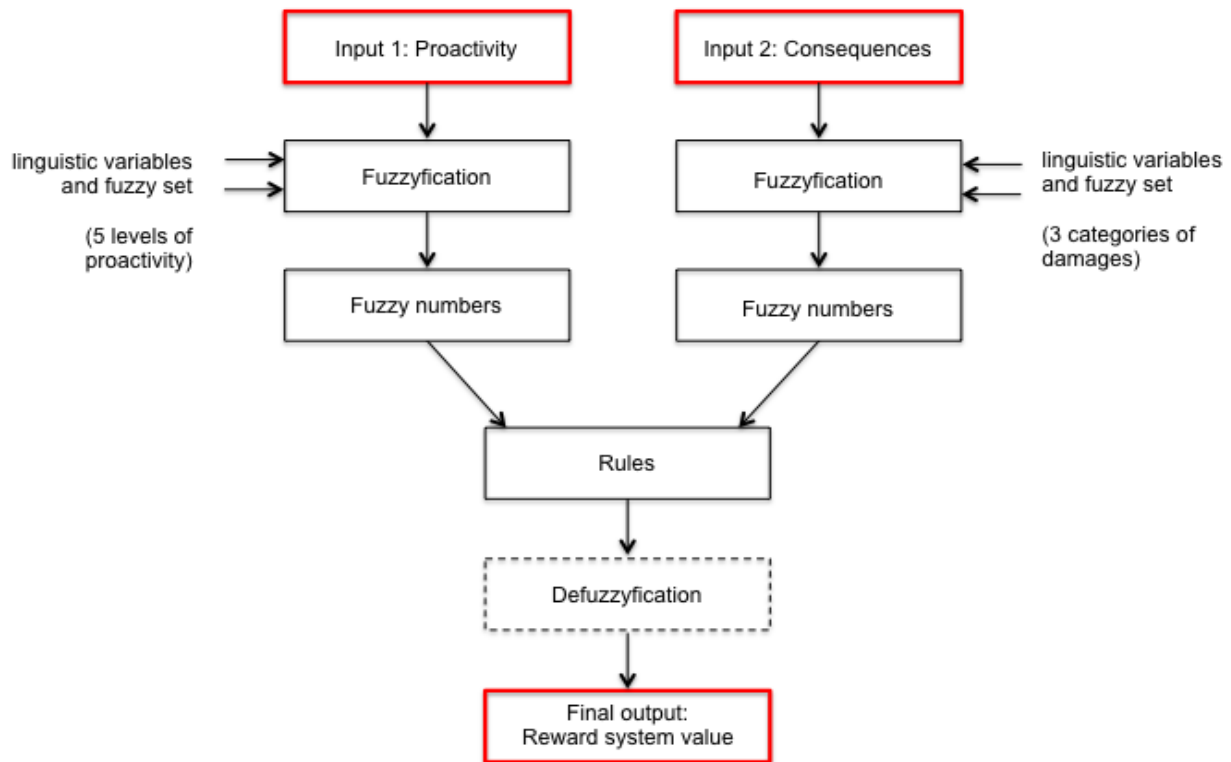


Figure 1: Scheme of the FIS building process for the assessment of the safety incentive.

The measure of both inputs can be gathered from each report, which contains different information about something wrong with reference to a procedure, a behavior or a general

failure of equipment. In fuzzy logic the measure of one variable requires the definition of some “linguistic variables”, which can be words or sentences in a natural or artificial language (Zadeh, 1975), used to describe the original variable.

For rating proactivity the linguistic variables selected are directly those reported in the first column of Table 1 (in the following for the sake of brevity each of them will be identified with the number of its level as reported in the table: L1, L2, etc...) and the procedure for its measure is based on the checklist developed for this study and reported in Appendix A. The checklist is focused on features of workers’ reports that can be used to quantify the proactive level of that behavior and each question has an increasing weight (from 1 to 15), in order to take into account that each one is representative of behaviours with an increasing proactivity level. Thus the sum of the weights of positive answers will be the initial measure of proactivity and the domain of the first variable will be [0; 120].

The second input variable is the priority of intervention required to avoid potential consequences. Three linguistic variables are introduced for its description, priority of intervention can be: “low” (referred as *green* class), “medium” (*yellow* class) and finally “high” (*red* class). This classification comes from the common practice of the company, where the methodology has been firstly applied, and where the priority of intervention is defined through a scale with 3 levels, identified by means of typical traffic lights. The green class identifies events for which the intervention for the reduction of the hazard can be postponed, because the possible related consequences are not severe. Instead the “red” class identifies an urgent intervention for those events that can pose a hazard for the health and safety of workers, or for the process safety, or also an environmental hazard; for instance in this class events that involve the potential spill of a large amount of a dangerous substances can be found. Also this variable is measured through a checklist, reported in Appendix B, which analyses workers’ reports in order to identify the magnitude of the possible consequences of the highlighted event. A preliminary rough knowledge of the colour representing the class is required in order to fill-in the checklist (provided by the company itself), which is divided in three sections, because the procedure requires that only one out of three sections of the checklist must be filled-in.

Finally three linguistic variables, or classes, have been selected for the output: “poor”, “modest” and “remarkable”.

3.2 Fuzzyfication of variables

The fuzzyfication process is done through the use of Fuzzy Sets (FS) and Membership Functions (MFs), a fuzzy set is a class of objects with continuous grades of membership (Zadeh, 1965), which are established through the MFs, that are functions correlating a numerical variable with a “degree of membership” to different linguistic variables.

In building this particular FIS, the fuzzyfication of proactivity passed through the construction of MFs that have been inferred from the meaning of proactivity and from the relationship that exists among its 5 levels (see section 2.1): each proactivity level can be seen as a subset of the previous one and it can be included in the next one. In terms of MFs, the resulting curves are those shown in Figure 2. The first membership function is represented by a rectangle (i.e. it covers the whole “universe of discourse”), because any report can be considered to be at least spontaneous. The MFs of the intermediate levels are trapezoidal and that of the higher level is a triangle. The final result is to assign to each report, not directly its score as it can be calculated straightforward from the checklist, but different degrees of membership to different proactivity levels. For example, a proactivity score of 30 will belong to the 3rd level (“anticipatory”, L3) with a degree lower than one, but it will belong also to classes L2 and L1 with a degree of membership of 1.

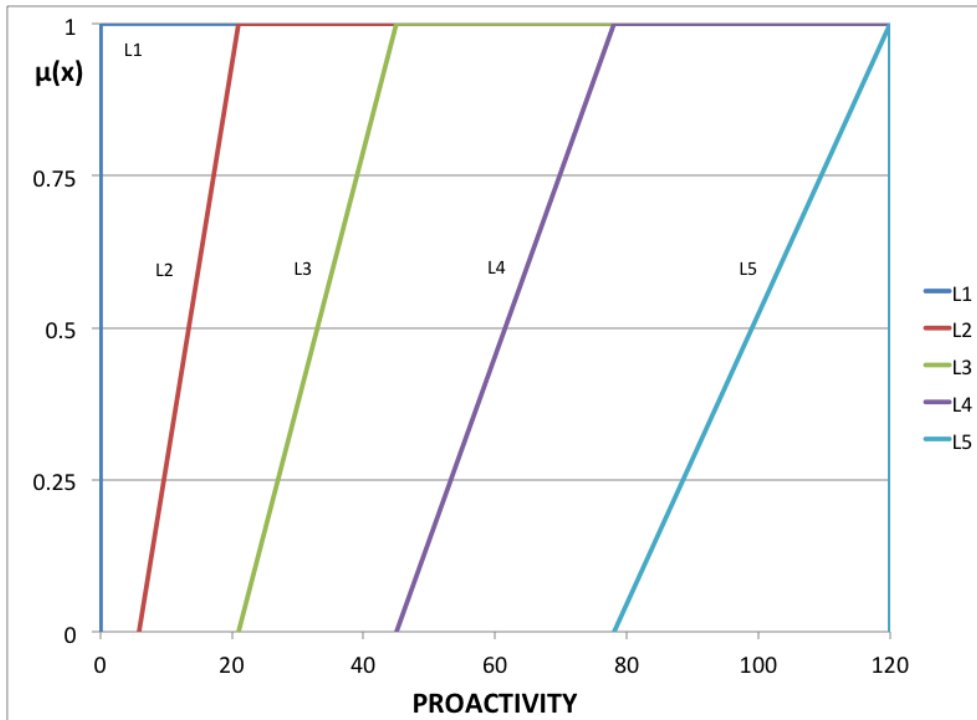


Figure 2. Membership functions for proactivity

Membership functions for the “priority of intervention” are different: three classes characterize this variable of the methodology and 3 trapezoidal functions have been selected (see Fig. 3). MFs have an overlapping zone where the score for the priority of intervention will result in two degrees of membership. The overlapping takes into account the vagueness of risk reporting, because it is a personal interpretation of perceived risk made by a human. For this reason if a report has a high degree of membership to a class, then it may belong with a little degree of membership also to the following one. Thus, even though an “a priori” knowledge of the class is required to answer the checklist, the vagueness of the information is still taken into account in the construction of the MF thanks to fuzzy logic approach.

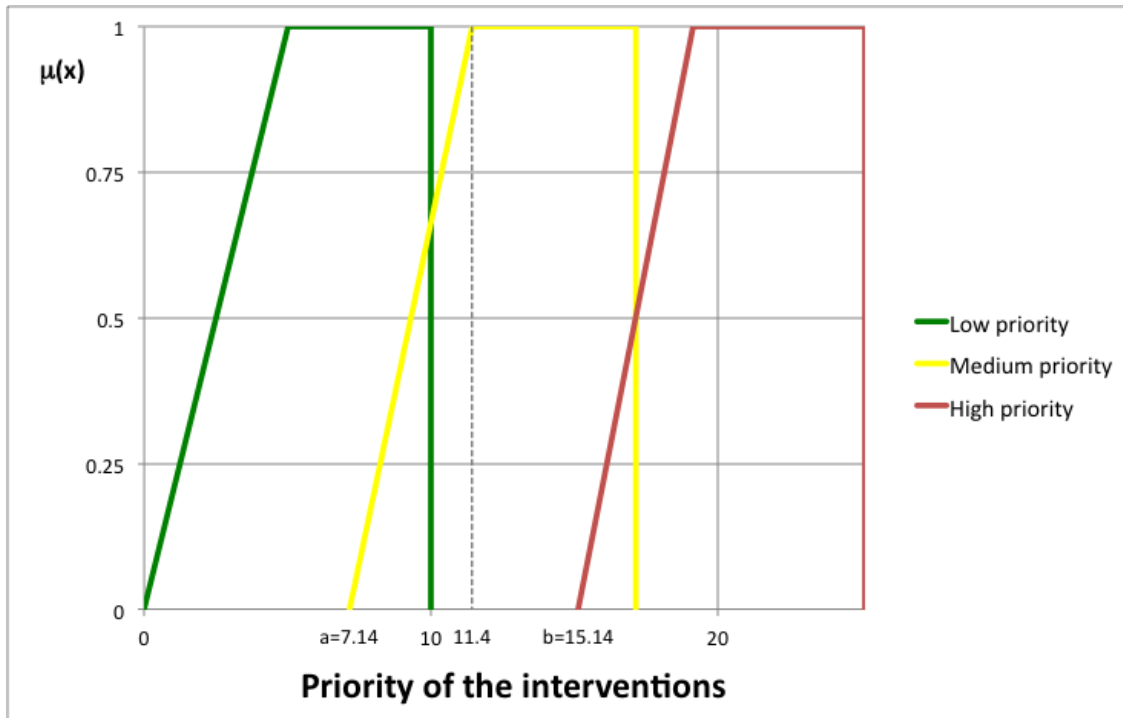


Figure 3. Membership functions for the priority of the intervention

In this particular application (since the quantification of this variable has been adapted to the type of company under consideration, due to the risks associated with the facility) the procedure to obtain a score for the priority of intervention is the following: once the class of the report is known, it is required to answer only to questions in the corresponding section (green, yellow or red) of the checklist. Four different answers to each question are possible, as reported in Appendix B, each corresponding to a score.

The total score of the answers must be added to a constant, which depends on the initial class (see also Figure 3): if the selected section is green the constant is 0; if the section is the yellow one, then the constant is $a = 7.14$; finally if the selected initial class is red, the constant is $b = 15.14$. The values of a and b derive first from having normalized the range for the score of each section, since the number of questions were different from one section to another (9 for the green class, only 7 for the yellow class and 10 for the red one) and then from other assumptions about possible uncertainties in the initial classification. When half of the questions in the green section of the checklist have a completely positive answer, the report can be assumed to be “completely green” and thus it belongs to the green class with the maximum degree of membership (see Figure 3). Then, in order to obtain the graduate shading (fuzzy) between the green and the yellow class, once that a signalling has been classified as yellow, it has been assumed that if only 2 positive answers out of 7 are completely positive, the signalling should be considered only “partly yellow” but still “completely green”. This means that the minimum x value, for which the priority of intervention simultaneously belongs to both classes, can be calculated as: $a = 10 - 2/7 * 10 = 7.14$ (see Fig. 3). The value 11.4 corresponds to the maximum degree of membership to the yellow class and it is given from 3 totally positive answers out of 7 questions ($11.4 = 7.14 + (3/7) * 10$). Similar considerations can be applied when shading from yellow to red class, but the adopted criteria are different and more conservative in order to give more importance to reported situations that can be potentially very dangerous: the number of positive answers to questions in the red section of the checklist that makes a report completely yellow and only partly red is 2 out of 10, while for the complete belonging to the red class at least 4 positive answers are required.

3.3 Fuzzy rules

Once the degrees of membership to the classes of proactivity and of priority of intervention are obtained through respective MFs, classes are used as inputs for the “fuzzy rules”. The fuzzy rules are of decisional type “If...then”, i.e. the symbolic incentive can be given to a worker if the premises are real; therefore, if the proactivity and the priority of intervention of a report activate the terms of the premises, the incentive will be one of the three classes.

In this work only the AND operator was used, also because it translates into a FIS the classical approach used in semi-quantitative risk assessment methodologies. Thus the number of rules that defines the model is $5 \times 3 = 15$ (Table 2). An example of rule is: “if the proactivity of the advisory meets with the features of the 4th level of proactivity (L4) AND the priority of intervention is red (R) then the symbolic incentive is remarkable (r). The consequence “incentive is remarkable” derives from the contemporary activation of the two terms that constitute the premises. The rule matrix reported in Table 2 contains all the rules, from which the class of the incentive for workers can be obtained. The matrix is a typical way of visually representing fuzzy rules when they are all defined using the AND operator, and they have been defined also on the basis of expert judgement by occupational risk analysts and with the help of the HSE management of the company.

		Priority		
P P		Green	Yellow	Red
Proactivity	L1	poor (1)	poor (2)	modest (3)
	L2	poor (4)	modest (5)	modest (6)
	L3	modest (7)	modest (8)	remarkable (9)
	L4	modest (10)	remarkable (11)	remarkable (12)
	L5	remarkable (13)	remarkable (14)	remarkable (15)

Table 2. Proactivity-priority-symbolic incentive matrix (rule numbers in brackets)

Finally, the output variable is represented by a class for the symbolic incentive. In Sugeno-type FIS (Sugeno, 1985), which has been selected for this methodology, a crisp output is generated from the fuzzy inputs and can be only either constant or linear. Constant numerical values arbitrarily associated to these classes are 1 for a poor incentive, 2 for the modest and 3 for the remarkable one.

The quantitative solution of the fuzzy system can be obtained using the Matlab fuzzy toolbox, which allows to quickly evaluate the output (incentive) as function of all the possible values in the range of the input variables (proactivity and priority of intervention). Results are reported in Figure 4 where, as expected, the value of the symbolic incentive increases when the level of proactivity and of the priority of intervention increase. From figure 4 is also evident that, since any advisory belongs anyway to the first level of proactivity, the incentive, which is calculated through a weighted average of all the values obtained from the activated rules, will never reach its theoretical maximum value (3, which means “exactly” remarkable). Anyway since numerical values for the incentive have been arbitrarily chosen, the resulting output can be differently scaled on the basis of a further application of the model on a significant number of workers’ advisories.

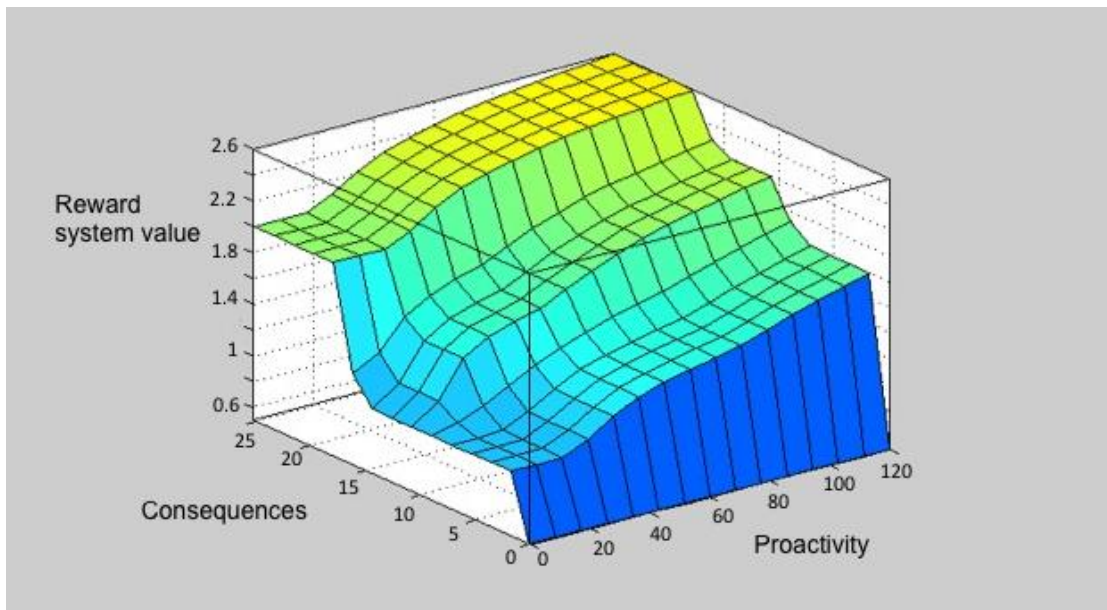


Figure 4. Symbolic incentive as function of both proactivity and priority of intervention

4. Case study

For this case study, the Italian facility of BASF in Pontecchio Marconi has been selected with the purpose to apply for the first time the proposed methodology. Over the period of 2011-2012, 357 events, including potential hazards and loss-of-time injuries, have been signalled by the workers in the register of the reports of the company; however none of them actually resulted in major injuries. Such a large number of reports is also the reason why it is very important for the management of the facility to rank and to organize these data, and this can be done through this methodology, which is able to take advantage of this kind of information. The procedure will be illustrated in detail for 3 selected reports, which have been analysed through the 2 checklists mentioned before and presented in Appendix A and B for proactivity and for consequences respectively. The values of the proactivity and of the priority of the intervention are calculated following the procedure described in the paragraph 3.2. Therefore for each advisory two values are the inputs to the model.

The first risk reporting of potential hazard taken into account mentions:

“The report concerns the discovery of cigarette butts inside a cabinet used for the storage of Individual Protection Devices (IPD).”

It was classified as green in relation with the importance of consequences due to insignificant urgency of the related intervention, then from the answers to the green section of the checklist the resulting score was 1.1. Proactivity is characterized by a value of 6: the first three questions of the checklist are satisfied because it is a spontaneous reporting activity of contingent risk factors in the workplace. The next levels would not be correct for describing the event since it substantially concerns simply the description of a hazard (fire hazard if the workers persist with this habit) and any solution to correct the problem is not proposed. On the basis of the fuzzy rules presented in paragraph 3.3 the resulting safety incentive is 1.

The second proposed risk reporting is:

“The report concerns the difficult access to the industrial refrigerator during maintenance operations. In particular, the operator must slip through pipes and

support structures thus, in case of an accident, first aid to the worker will be difficult.”

The score of this second signalling is 9 for the priority of intervention, thus it actually belongs completely to the green region but also partially to the yellow one, though it was preliminary classified as yellow. Then it satisfies the first and the second level of proactivity because there is a spontaneous reporting activity, and a self-started problem solving process to correct the anomaly can be identified, but there is not an anticipatory attitude related to the possible future consequences. The corresponding score for proactivity is 20. The resulting symbolic incentive is 1.15, which means an incentive slightly higher than “poor” in terms of linguistic variables.

Finally the third report is used to better explain in detail how this FIS works also with the aid of Figure 5. The signalling mentions:

“The report concerns the spill of a product at high T and P from an obstructed air valve. So an injury to the employee that works near the valve is possible.”

The report, on the basis of the answers to both checklists, has a proactivity score of 5 (reported in the leftmost part of Figure 5) and a score of 16.5 for the priority of intervention (central part of the figure). When proactivity is equal to 5 its degree of membership to the first level is equal to 1 and it is 0 to any other proactivity level, but for the priority of intervention, the system assigned a degree of membership equal to 1 to the yellow category and also a non-zero degree of membership to the red one. This means that rules 2 and 3 are activated (highlighted in the box of Figure 5) and that the symbolic incentive has the maximum degree of membership to the class “poor” but it also belongs, though to a lower extent, to the class “modest” (bars in the rightmost part of Figure 5) and the HSE management of the company could still decide whether to assign the first or the second class of incentive. A corresponding numerical value can also be calculated (1.25) from a weighted average (no defuzzification was assumed) of the values obtained for the classes. Though this one was the most severe report in terms of priority of intervention, among the three selected, its low proactivity value does not allow the incentive to be completely at least “modest”.

From the analysis of these three reports it seems quite clear that proactivity plays, as expected, an important role in the definition of the incentive in this reward system, since all the three situations analysed showed a very low level of proactivity and therefore none of them has reached at least completely a “modest” incentive. Nevertheless the model seems to be adequate in taking into account future improvements in the workers’ behavior.

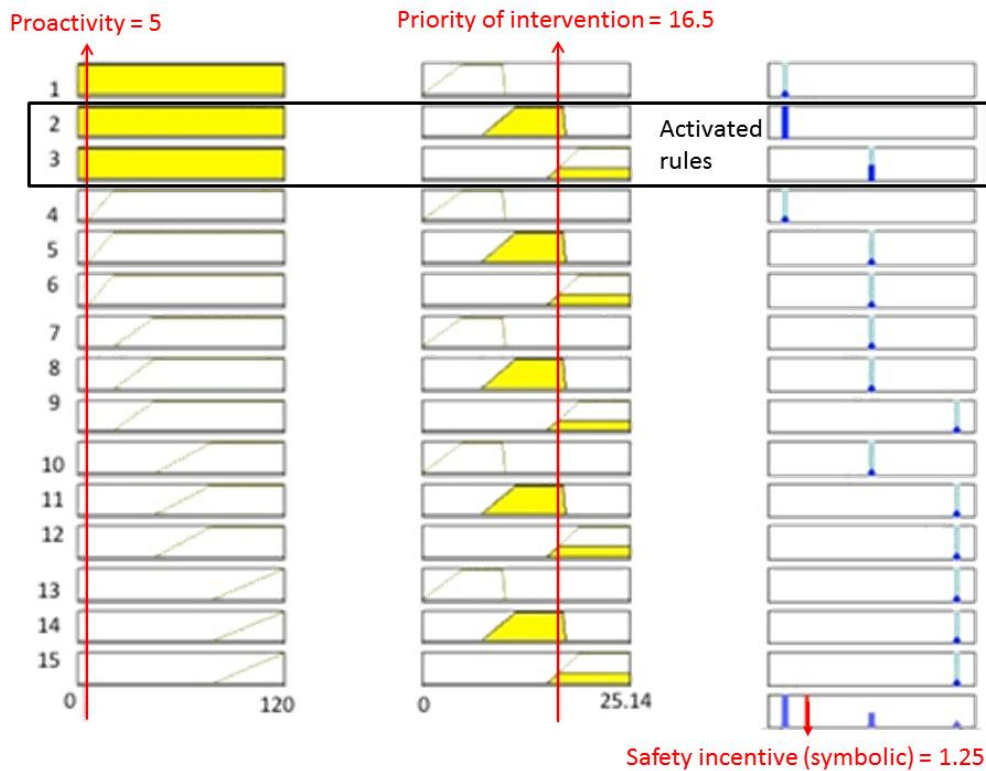


Figure 5. Results for the 3rd selected advisory in the case-study

5. Results and discussion

A first interesting outcome of this first application of PCBSI model was the dramatic increase of reports about potential hazardous events. While some reward programs indirectly discourage workers from reporting accidents and cause an under-reporting problem (because the incentive is assigned on the basis of the absence of injuries), with the proposed approach, the safety incentive is assigned on the basis of the reporting activity itself, which should avoid the accidents occurrence, and thus possibly only an opposite (and less critical) over-reporting situation may be observed from its application. This growth of reporting activity also made available for the company a lot of data, from which monitoring safety standards and planning maintenance interventions, but reports should be conveniently selected and the methodology can also be a useful tool in order to rank and select relevant reports.

PCBSI reward system can also be applied at workgroup level, in order to evaluate the behavioural outcome of working units or teams, especially by setting common goals to teams, because single proactive behaviour is to be differentiated from group level proactive behaviour. Griffin, Neal and Parker (2007) underlined such difference and took into consideration team member proactivity, which is the extent to which an individual engages in self-started and future-oriented behavior in order to influence and modify the way the team works. The authors found that team supportiveness is an antecedent to team member behaviours like team member proficiency, team member adaptability, and team member proactivity. This suggests that a reward system like the one proposed in this work, if integrated in an environment that fosters group supportiveness, should help in increasing group proactivity and ultimately in changing the behavior of teams and single individuals.

Finally, the incentive was measured through a value, which, though symbolic, has an extrinsic meaning, because extrinsic motivation should not be overlooked even if in favour of the more recognized effectiveness of intrinsic one. PCBSI model is therefore a useful tool that enables to

clearly quantify the proactive level of behavior and provides a useful framework to distribute monetary or similar extrinsic rewards also in a measurable and equitable way.

6. Conclusions

This research drew its inspiration from risk reporting activity and from risk perception in workplaces. The method here presented could enrich the range of instruments available to organizations and, among areas of human resources for safety, it could be applied especially in the area of compensation, which brings a certain advantage in terms of competitiveness to the organization (Lawler, 2000) and this is why human resource departments tend to advise the use of these systems.

The aim of the PCBSI model is to build a methodology whose long-term implementation should decrease occupational accidents and injuries. Thus, it is the first step for the realization of a leading method for the prevention of occupational risk. The method is based on the implementation of a reward system (not necessarily monetary), in order to enhance occupational safety, starting from a participatory contribution by workers in safety promotion. The model measures this contribution through spontaneous risk-reporting activities.

It is important to underline that the PCBSI reward program, to be fully effective, should be integrated in an organizational context that is already adopting proper safety education and training, or at least should be introduced in parallel with some organizational change going into such direction.

Under this assumption, a program based on PCBSI presents different advantages, for managements and organizations, as it allows: a) to monitor the actual anticipatory tendency of active risk management at the shop-floor level b) to identify weakest points in safety participations in different organizational sectors c) to identify valid solutions for safety improvement in specific sectors that can be generalized in the whole plant d) to incentive virtuous behaviors and initiatives, by workers and teams.

Some aspects of the methodology can be further improved especially in order to provide a generalized procedure for assessing potential consequences: at management level the overall economic loss avoided thanks to a risk report could be calculated both in terms of lost days due to injuries to workers and in terms of maintenance and repair of damages to the equipment; nevertheless the methodology is also able to identify, at an individual level, where and how to strengthen learning levers, since cases with a low level of proactivity during operations could be pointed out and stimulated using the reward system.

Acknowledgements

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Appendix A: Checklist for Proactivity

Possible answers: yes/no (yes = 1, no = 0)

1. Is the operator's advisory actually voluntary (or rather not expected by his job responsibility)?
2. Has the worker spontaneously advised the hazardous event in question (without suggestions from co-workers)?
3. Has the worker advised the event without having previously received specific instructions by the company?
4. Has the worker given suggestions to solve the event?
5. Has the worker tried to solve by him/herself the event?
6. Has the worker tried to reduce the hazard?
7. Was the event actually unpredictable without the worker advisory?
8. Does the worker give useful information to forestall the negative consequences of the event?
9. Does the worker give useful information to forestall the problem in the future?
10. Does the worker give suggestions to face the problem in the future?
11. Does the worker give efficient suggestions to avoid the event in the future?
12. Has the worker actually supplied innovative suggestions (not currently contemplated) to avoid the event in the future?
13. Does the worker suggest or produce a solution that induces an improvement/increase of the safety regarding his work shift?
14. Does the worker suggest or produce a solution, which enhances the safety, that can be extended to the whole department?
15. Does the worker suggest or produce a solution, which enhances the safety, that can be extended to the whole plant?

Appendix B: Checklist for the Priority of the intervention

Possible answers:

totally agree – score = 1

partially agree – score = 0.67

partially disagree – score = 0.33

totally disagree – score = 0

Section one: Green region

1. Does the advisory concern the possible presence of a waste to give back, or a claim?
2. Does the advisory concern the possible presence in the temporary storage area of unsuitable liquids for the waste treatment plant?
3. Does the advisory concern the possible spill (< 10 kg) of a classified substance (like a chemical substance) different from CYC (cyanuric chloride)?
4. Does the advisory concern the possible spill (< 20 kg) of a not classified substance (like water)?
5. Does the advisory concern the possible failure of a RD (Rupture Disk) or safety valve of unclassified equipment?
6. Does the advisory concern a potential first aid for the company employees?
7. Does the advisory concern a potential LTI (Loss Time Injury) for a contract worker (external worker/contractor)?
8. Does the advisory concern a possible deviation from the correct operation of the biological plant?
9. Does the advisory concern an event for which it is necessary to identify actions, but they can be managed without urgency?

Section two: Yellow region

1. Does the advisory concern the possible spill (> 10 kg but < 100 kg) of a classified substance?
2. Does the advisory concern the possible spill (< 5kg) of CYC (cyanuric chloride)?
3. Does the advisory concern the possible failure of a RD (rupture disk) or of a safety valve on an equipment holding a substance with a Risk Phrase?
4. Does the advisory concern the possible/potential refilling of emergency tank?
5. Does the advisory concern a potential injury for a contract worker (external worker/contractor)? (LTI with first aid for the injury related to the job activity and not generated from site activity interference)
6. Does the advisory concern a potential injury for the employees of the company? (LTI not related to the job activity or an injury, non LTI, related to the job activity)?
7. Does the advisory concern an event for which it is necessary to schedule actions?

Section three: Red region

1. Does the advisory concern the possible spill of BTC ($\alpha\alpha\alpha$ -trichloro toluene) or NH₃ or hot conductive oil (hot diathermic oil)?
2. Does the advisory concern the possible spill (> 5 kg) of CYC?
3. Does the advisory concern the possible spill (> 100 kg) of a classified substance?
4. Does the advisory concern the possible spill (> 2000 kg) of a not classified substance?
5. Does the advisory concern an event which can cause a fire, an explosion/implosion?
6. Does the advisory concern an event which can cause a possible environmental impact?
7. Does the advisory concern a possible RD failure (Rupture Disk) or safety valve failure or concern a possible reaction deviation of a substance with a Risk Phrase?

8. Does the advisory concern an event with possible crossing of inner thresholds for air matrix and water matrix?
9. Does the advisory concern a potential injury (permanent inability or death)? (LTI and first aid for injury related to the job activity for the employees of the company, for the contractors only if it is caused by a site inference activity)
10. Does the advisory concern an event which can draw the media attention?